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What is Missing Between Agricultural Growth and Infrastructure Development?

Cases of Coffee and Dairy in Africa

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Abstract

Although it is commonly believed that aggregate economic growth must be associated with public infrastructure stocks, the possible infrastructure needs and effects are different from industry to industry. The agriculture sector is typical. Various infrastructures would affect agriculture growth differently depending on the type of commodity. This paper finds that a general transport network is essential to promote coffee and cocoa production, perhaps along with irrigation facilities, depending on local rainfall. Conversely, along with the transport network, the dairy industry necessitates rural water supply services as well. In some African countries, a 1 percent improvement in these key aspects of infrastructure could raise GDP by about 0.1–0.4 percent, and by possibly by several percent in some cases.

This paper—a product of the Finance, Economics and Urban Development Department—is part of a larger effort in the department to examine agricultural evolution, infrastructure development and economic growth. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at aiimi@worldbank.org.

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Produced by the Research Support Team

WHAT IS MISSING BETWEEN AGRICULTURAL GROWTH AND INFRASTRUCTURE DEVELOPMENT?[¶]

CASES OF COFFEE AND DAIRY IN AFRICA

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I. INTRODUCTION

It is natural to expect that aggregate agricultural growth is positively related to infrastructure development. However, how to strengthen such a relationship at the operational level remains debatable. Specifically, it is questionable what type of infrastructures need developing to promote agricultural production and competitiveness. Which farm product is the most important to stimulate overall growth and reduce poverty in developing countries? The current paper, casting light on the significance of agriculture in Africa, aims at examining the potential effects of infrastructure development on agricultural growth.

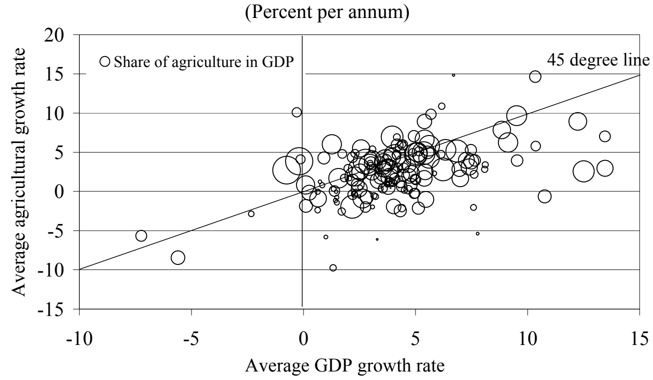
Following the general overview, the paper will pay particular attention to two commodities that are differently characterized at various levels: coffee and cocoa, and dairy—essentially cow milk. Sub-Saharan Africa is the geographic focus of this paper because the region is and will continue to be relatively heavily dependent on the agricultural sector into the foreseeable future. However, the empirical results are relevant to other regions as well. Methodologically, the paper takes the middle course between the micro and macro perspectives in the sense that it estimates the supply and demand system for a given commodity, while relying on existing aggregate data. There are considerable data limitations to directly answer the above-mentioned questions, and the possible answers may vary across commodities and across countries.[1] However, it can be shown that infrastructures would influence coffee and dairy production differently, and different infrastructure services have to be improved to accelerate agricultural growth.

The potential of agriculture to contribute to the overall growth of economies in Africa is regarded as high. However, in general, under current contributions such growth seems very moderate. Over the past five years about 75 percent of the countries whose data are available achieved relatively low growth rates in agriculture, compared with nonagricultural sectors

[1] If there existed sector-specific input variables, the empirical growth model could be applied for agriculture sector growth. However, it is difficult to obtain sufficient data representing agriculture-specific physical and human capital and other macro variables, though some data on agricultural employment may be available.

(Figure 1).[2] [3] Why is agricultural development lagging behind? One reason may be that agricultural production tends to be inefficient; the total factor productivity growth in agriculture is usually low, particularly in developing countries (e.g., Bravo-Ortega and Lederman, 2004).[4] It could also be attributable to large migration of labor force from agriculture to nonagriculture, as often expected as the economy develops. A decline in agricultural labor input directly restrains the agriculture sector growth.

Figure 1. GDP growth and agricultural growth, 2001-2005
(Percent per annum)



Source: *World Development Indicators.*

Lack of adequate infrastructure might be another reason for stagnant agricultural productivity improvement. Infrastructure stocks have normally been found conducive to economic development because infrastructure improvements could reduce transportation and transaction costs for producers (e.g., Canning, 1998; Fay and Yepes, 2003; Calderón and

[2] Notably, there may be a causality issue between agriculture and nonagricultural growth. Bravo-Ortega and Lederman (2005) indicate that agricultural growth Granger-causes nonagricultural growth, and vice versa.

[3] The figure also reflects the significance of the agriculture sector in each economy. It is natural that in countries with higher dependency on agriculture, GDP growth is more easily affected by the agricultural growth rate. But there is no systematic trend associated with the size of the agriculture sector.

[4] Notably, Schultz (1964) argued that traditional economies were "efficient but poor." Farmers and other producers in these economies don't have much, but they make good economic use of what they have. In the growth accounting context, however, recent empirical agriculture economics has found that physical inputs, particularly capital would explained the majority of growth in agriculture, along with human capital investment (i.e., schooling). Bravo-Ortega and Lederman (2005) and Tiffin and Irz (2006) also find the evidence that agricultural value added (Granger-)causes economic growth in developing countries. As far as total factor productivity is concerned, however, it seems to be very limited on the order of 10 percent of the total agriculture growth (e.g., Mundlak, 2000).

Servén, 2004).[5] For the same reasons, more agriculture-related infrastructures are expected to reduce farmers' costs and accelerate growth in agriculture (e.g., Antle, 1983; Mundlak *et al*., 2004; Gardner, 2005). Investments in rural infrastructure are often deemed as most effective to promote agricultural growth and reduce poverty, along with agricultural research and education (Fan *et al.*, 2002; World Bank, 2005).

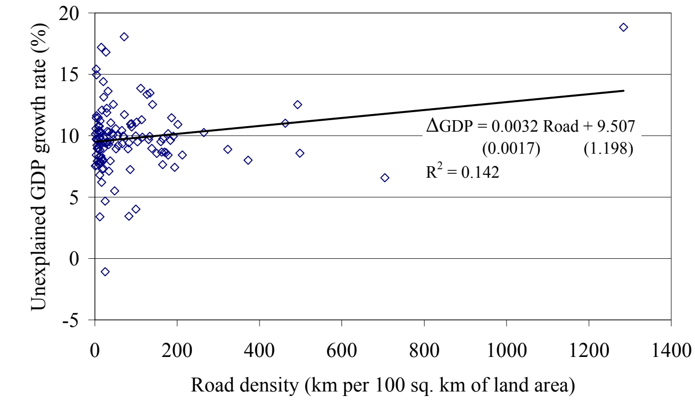
However, the empirical linkage between agricultural growth and infrastructure is not easily demonstrated. Figure 2 depicts the relationship between a proxy of infrastructure stocks—i.e., road density—and unexplained (compound annual) growth after controlling for the initial level of economic development measured by per capita GDP in logarithm. As expected, there is a significant positive relationship between these two variables.[6] By contrast, the same specification yields a negative association when accounting for only agricultural growth (Figure 3). Thus, accumulated transport infrastructure seems to play a significant role in encouraging overall economic development but not agricultural growth. Notably, as shown in Table 1, the above contrast is not characteristics of only the road density but almost common despite the choice of infrastructure variables (i.e., electric power consumption and teledensity).[7]

[5] Calderón and Servén (2004) show that growth is generated by the quantity of infrastructure stocks but not by the quality of infrastructure. However, there might be a practical sense that the quantity would likely matter at the earlier stage of development, and then the quality would become more important later on.

[6] On a level basis, obviously, there is a strong correlation between GDP and infrastructure stocks (e.g., World Bank, 1994). On one hand accumulated public infrastructure would improve economic efficiency and increase GDP, and on the other hand higher national income would afford more investment in infrastructure.

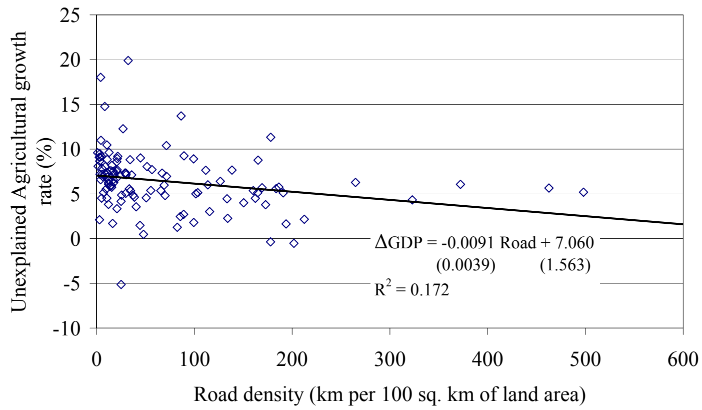
[7] When the share of population with access to improved water sources is used for infrastructure, both GDP and agricultural growth have been found insignificantly associated with the infrastructure proxy.

Figure 2. GDP growth and infrastructure stock



Source: Author's estimation.

Figure 3. Agricultural growth and infrastructure stock



Source: Author's estimation.

Table 1. Impact of general infrastructure stocks on overall and agricultural growth, 2001-05

	Avg. GDP growth $_{2001-05}$					Agricultural GDP growth $_{2001-05}$				
ln GDP $_{2000}$	-0.710 ***	-0.804 ***	-0.967 ***	-1.068 ***	-0.481 **	-0.522 **	-0.786 ***	-1.089 ***	-0.475	-0.731 ***
	(0.159)	(0.199)	(0.210)	(0.289)	(0.192)	(0.217)	(0.259)	(0.296)	(0.371)	(0.222)
Road density	0.0032 *					-0.009 **				
	(0.0017)					(0.004)				
Share of paved roads		0.018 **					0.003			
		(0.010)					(0.012)			
Electricity consumption			0.00014 **					0.00004		
			(0.00007)					(0.00009)		
Teledensity				0.0021 **					-0.0009	
				(0.0008)					(0.0011)	
Water access					-0.006					-0.009
					(0.016)					(0.018)
Constant	9.507 ***	9.578 ***	11.337 ***	10.823 ***	7.982 ***	7.060 ***	8.365 ***	10.941 ***	6.543 ***	8.676 ***
	(1.198)	(1.290)	(1.490)	(1.762)	(1.163)	(1.563)	(1.685)	(2.097)	(2.242)	(1.378)
Obs.	124	114	125	177	161	116	105	116	160	148
R-squared	0.142	0.133	0.174	0.087	0.076	0.172	0.117	0.129	0.116	0.130
F statistics	9.97	8.51	12.86	8.29	6.51	11.75	6.74	17.17	10.26	10.83

Source: Author's estimations.

Note that the dependent variables are the five-year average GDP growth rate and agriculture sector growth rate, respectively. The standard errors are shown in parentheses.

*, **, and *** indicate the 10%, 5% and 1% significance levels, respectively.

There are many potential reasons for this poor relationship between infrastructure and agricultural growth. First, aggregation of agricultural outputs may not be suitable for addressing a question on the infrastructure impact on farming productivity. One of the most traditional approaches in this area is to estimate an aggregate production function of agriculture (e.g., Antle, 1983; Mundlak *et al*., 2002; Mundlak *et al*., 2004; Bravo-Ortega and Lederman, 2004). However, such estimates may not be straightforward to be interpreted from the governmental policy point of view, unless only one farm product is sufficiently dominant in the economy.[8] Each agricultural product must have a unique production function and thus require different inputs. For the same reasons, it is also unlikely that different commodities would benefit identically from a particular type of public infrastructure.

Second, the conventional infrastructure variables may also be inappropriate in the sense that they do not represent agriculture-specific infrastructure. For instance, agricultural growth is unlikely to be stimulated even if water access is improved. This is because the majority of agricultural activities are concentrated on rural areas while water access mostly benefits urban dwellers.[9] Most direct agriculture-related "infrastructure" may be rural roads and irrigation if applicable (World Bank, 2005; Williams *et al*., 2006; Buys *et al*., 2006; Broadman, 2007). Without effective access to the input and output markets, agriculture production could not be viable. In this context, the most relevant infrastructure proxy would be the "rural access index" (Roberts *et al*., 2006). Irrigation water is a major input to traditional staple crops; a good proxy may be the share of irrigated land to total cropland, which is available by *World Development Indicators* (*WDI*) or *FAOSTAT*.

Infrastructure that farmers indirectly rely on differs from commodity to commodity. If inputs and outputs are mass-transported, railways may be an essential infrastructure. If a modern

[8] The production function estimation approach *is* advantageous to investigate the (very) long-run overall productivity growth in agriculture, e.g., total factor productivity, with relatively less constrains on data requirement.

[9] Even by the traditional aggregate infrastructure proxies, overall growth would be affected differently. Calderón and Servén (2004) show that growth is promoted especially by telecommunications network development. This is basically consistent with Fay and Yepes (2003), which investigate the reverse direction.

system of "factory farming," which requires various inputs and agricultural machinery, is adopted, production efficiency would be affected by electricity and water supply infrastructure. If informational market access is important for effective production and export purposes, a telecommunications network is essential (Timmer, 2002; Williams *et al*., 2006). Lio and Liu (2006) show that the elasticity of information and communication technology is approximately 0.21, meaning that a 1 percent increase in Internet, personal computer, cellular phone or fixed line users would raise total agricultural value added by 0.21 percent.

Moreover, the possible complementarity between types of infrastructure may complicate the assessment of growth effects of infrastructure investment. A large investment in irrigation without roads does not make sense if roads are essential for access to the market.

Finally, the last possible reason for failure to capture a positive agriculture-infrastructure linkage is the uncontrolled endogeneity and omitted variable problems; without dealing with them adequately, the true impact of infrastructure on agricultural production cannot be estimated. There are at least two approaches to solve these issues: partial and general equilibrium. The former, as typically adopted in the industrial organization and agricultural economics literature, focuses on the market structure and performance. It estimates the supply and/or demand functions of particular merchandise, especially investigating price elasticities, using an instrumental variable technique (e.g., Morrison, 1997; Reed and Saghaian, 2004).[10] As per Delgado *et al*. (2005), the poor quality of transport infrastructure hampers efficient pass-through of wheat, rice, maize and cassava prices in Tanzania. Iimi (2007) also shows that quality roads and electricity infrastructure could significantly reduce beef production and export costs.

On the other hand, the general equilibrium approach establishes a set of structural equations in broader circumstances and analyzes the detailed interactions that would occur among the variables included in the model. With provincial-level data in China, Fan *et al*. (2002),

[10] All production and cost function models mentioned above could be categorized into this.

modeling the poverty, wage, production, investment, and terms of trade equations, estimate returns of different public investments to growth and poverty reduction. They find that agricultural research and development (R&D) and education would considerably increase agricultural GDP, and that public road and telecommunication investment would more benefit nonagricultural growth. The results for Thailand are more or less the same (Fan *et al*., 2004). A computational general equilibrium (CGE) model is also considered as a version of this general approach (e.g., Nordås, 2004; Mlachila and Yang, 2004; USITC, 2004).

The following analysis adopts the partial equilibrium approach with agricultural trade data. This approach has the advantage of relatively low data requirements and high tractability; based on micro-foundations, it can easily focus on specific issues in question. Though, it may overlook some possible side effects that would occur in the economy beyond the model. In contrast, the general equilibrium approach is good at providing a broad picture of the economy but will risk complicating the structural specification and requiring much extensive data; it preferably requires disaggregate data on the sub-national level. Concern also grows over misspecification and critical omitted variables, as the model includes more equations. Moreover, the "black-box" criticism, to which the CGE model is typically vulnerable, would be applicable.

The paper attempts to relate product market outcomes to agricultural-related infrastructures for two commodities: coffee (together with cocoa in our following empirical specification), and dairy. These are economically and socially important in Africa. In addition to the traditional infrastructure variables, various agricultural (or rural) infrastructure proxies are examined: rural telecommunications adoption index, rural water access, electricity consumption for agricultural purposes, and rural access index.

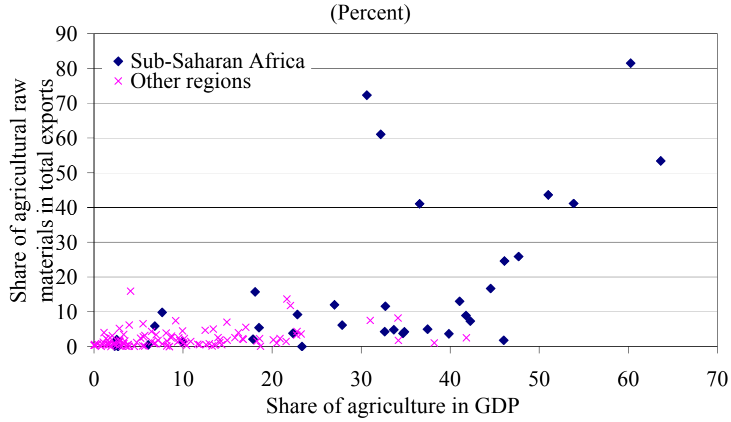
The following sections are organized as follows. Section II describes an overview of agriculture in Sub-Saharan Africa. Section III develops an empirical model to estimate the supply and demand functions of each farm product. Section IV quantifies the infrastructure effects on the production and export of coffee and cocoa, and milk, and discusses some policy implications for African countries when comparing those two cases.

II. Overview of Agricultural Production and Infrastructure In Africa

The significance of agricultural production in the economy is high in Sub-Saharan Africa. In that region 12 out of 36 countries whose data are available have agricultural shares of GDP greater than 30 percent *and* agricultural contribution to total exports greater than 10 percent; whereas this magnitude of agriculture contribution to GDP is not achieved for any country in other regions (Figure 4). It means that agricultural sector development remains crucial for growth in Africa. The challenging of achieving this growth seem even more difficult when taking into account the fact that African countries have achieved systematically rather lower agricultural growth than other regions (Gardner, 2005).

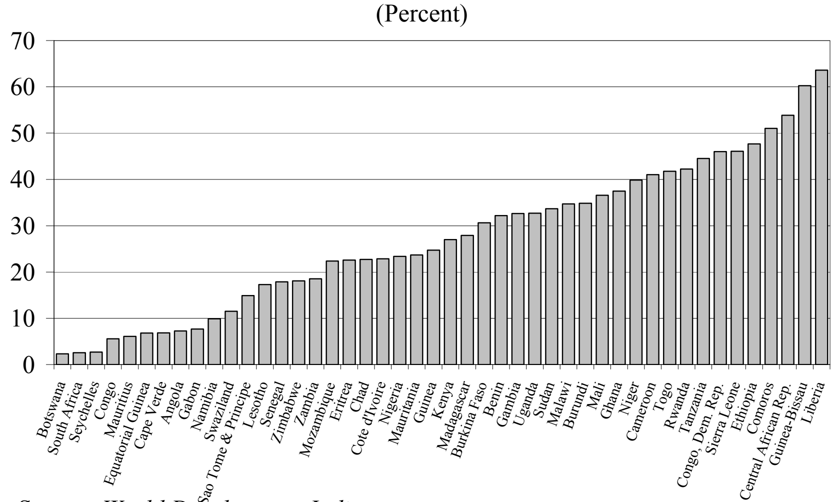
It is no less important that the dependency varies from country to country even within the region. Some countries, such as Guinea-Bissau and Liberia, heavily depend on agriculture (accounting for about 60 percent of GDP), while in others such as Botswana and South Africa it is less than five percent (Figure 5). Normally, those countries having relatively low dependency on agriculture tend to be natural resource-rich economies in the region.

Figure 4. Share of agriculture in GDP and total exports
(Percent)



Sources: *World Development Indicators* ; and author's estimates.

Figure 5. Sub-Saharan Africa: Share of agricultural output in GDP, 2003-05
(Percent)



Source: *World Development Indicators.*

What does Africa produce in agriculture? Table 2 indicates some major agricultural items that African countries are producing. On a regional aggregate basis Africa mainly supplies traditional staple crops, such as cereal, cassava, sugar, maize, yams and rice. Besides grains and root crops, cocoa and coffee, meat (beef, veal and chicken) and fruits (bananas, oranges and papayas) are also important. Dairy (cow and goat milk) is increasingly gaining in importance as an agricultural commodity in the region.

From the exports point of view, there are five important commodities produced in Africa: (i) coffee, cocoa and tea, (ii) cotton-related commodities, (iii) livestock products, (iv) tobacco leaves and products, and (v) sugar. Table 3 includes the three largest agricultural items exported from African countries whose economies are heavily dependent on agricultural production; the threshold is 30 percent of GDP. Vanilla from Comoros and natural rubber from Liberia appear exceptional in the region.

Table 2. Major agricultural products in Africa, 2004

Product	Volume (Millions of tons)	% of world production
Cereals	121.4	5.9
Cassava	108.1	53.3
Sugar cane	84.6	6.4
Maize	43.4	6.0
Yams	38.3	95.7
Plantains	23.2	71.3
Cow milk, whole, fresh	21.8	4.2
Wheat	21.7	3.5
Sorghum	21.0	35.7
Rice, paddy	18.9	3.1
Oil palm fruit	15.8	9.8
Millet	14.3	49.6
Potatoes	14.0	4.3
Tomatoes	13.7	11.4
Sweet potatoes	11.3	8.9
Groundnuts in shell	8.8	24.7
Taro (coco yam)	8.2	77.3
Bananas	6.8	9.5
Seed cotton	5.2	7.2
Oranges	5.0	8.0
Onions, dry	4.3	7.8
Beef and veal	4.2	7.1
Watermelons	4.1	4.3
Chicken meat	3.2	4.7
Mangoes	2.6	9.9
Cocoa beans	2.6	72.4
Pineapples	2.6	17.0
Papayas	1.3	20.0
Coffee, green	1.0	13.1

Source: *FAOSTAT*.

Table 3. Significance of the agriculture sector in Sub-Saharan African countries

Country	Share of agriculture (2003-05) % of GDP	% of total exports	Three major agricultural exports (2001) Product	Amount (mil. US$)	% of GDP	Product	Amount (mil. US$)	% of GDP	Product	Amount (mil. US$)	% of GDP
Benin	32.2	61.0	Cotton Lint	118.8	5.0	Cashew Nuts	11.1	0.5	Palm Oil	8.5	0.4
Burkina Faso	30.6	72.3	Cotton Lint	102.8	3.7	Cattle	16.9	0.6	Fruit Tropical Fresh N	12.0	0.4
Burundi	34.8	4.2	*Coffee, Green*	*21.1*	*3.2*	Tea	6.8	1.0	Beer of Barley	1.3	0.2
Cameroon	41.1	13.0	*Cocoa Beans*	*116.7*	*1.2*	Cotton Lint	101.2	1.1	*Coffee, Green*	*76.0*	*0.8*
Central African Republic	53.9	41.2	Cattle	12.0	1.2	Cotton Lint	6.9	0.7	*Coffee, Green*	*1.9*	*0.2*
Comoros 1/	51.0	43.6	Vanilla	5.7	2.6	Cloves, Whole & Sten	1.6	0.7			0.0
Congo, Dem. Rep. 1/	46.0	1.8	*Coffee, Green*	*3.2*	*0.1*	Tobacco Leaves	2.4	0.1	*Cocoa Beans*	*2.4*	*0.1*
Ethiopia	47.7	25.9	*Coffee, Green*	*135.0*	*1.7*	Sesame Seed	9.7	0.1	Sugar (Centrifugal, Ra	8.0	0.1
Gambia, The	32.6	4.3	Oil of Groundnuts	5.5	1.3	Groundnuts Shelled	4.8	1.1	Oil of Linseed	2.1	0.5
Ghana	37.5	5.0	*Cocoa Beans*	*396.0*	*7.5*	Cocoa Butter	17.3	0.3	Cigarettes	15.0	0.3
Guinea-Bissau 1/	60.3	81.5	Cashew Nuts	47.0	23.6	Cotton Lint	3.6	1.8	Cottonseed	0.2	0.1
Liberia 1/	63.6	53.4	Rubber Natural Dry	65.5	12.1	Palm Oil	2.1	0.4	*Cocoa Beans*	*0.8*	*0.1*
Malawi	34.7	3.8	Tobacco Leaves	256.9	15.0	Sugar (Centrifugal, Ra	52.2	3.0	Tea	34.1	2.0
Mali 1/	36.6	41.0	Cotton Lint	172.0	6.5	Cattle	80.0	3.0	Sheep	18.0	0.7
Niger	39.9	3.6	Cattle	16.0	0.8	Sheep	11.8	0.6	Goats	10.5	0.5
Rwanda	42.3	7.3	Tea	16.5	1.0	*Coffee, Green*	*14.9*	*0.9*	Hides and Skins	0.7	0.0
Sierra Leone 1/	46.1	24.6	*Cocoa Beans*	*2.6*	*0.3*	*Coffee, Green*	*1.7*	*0.2*	Cigarettes	0.6	0.1
Sudan	33.7	4.8	Sesame Seed	94.8	0.7	Cotton Lint	41.1	0.3	Sugar Refined	21.0	0.2
Tanzania	44.5	16.7	*Coffee, Green*	*63.8*	*0.7*	Cashew Nuts	63.3	0.7	Tobacco Leaves	41.5	0.4
Togo	41.8	8.9	Cotton Lint	45.0	3.4	Cotton Carded Combe	18.6	1.4	Flour of Wheat	8.5	0.6
Uganda	32.7	11.6	*Coffee, Green*	*51.3*	*0.9*	Tea	16.2	0.3	Tobacco Leaves	15.8	0.3

Sources: *FAOSTAT*; *World Development Indicators;* and author's estimates.
1/ The share of agriculture in total exports is for 2001.

In the growth context, agricultural exports and commodities which are primarily consumed domestically (as shown in Tables 2 and 3) are characterized much differently. The following empirical work analyzes two groups of commodities: coffee and cocoa, and cow milk; they are chosen because of their significant but different roles in the African economy. Coffee and cocoa are among high-value agricultural commodities, which require significant land holdings and are mass-produced almost entirely for export, mainly to European countries.[11]

In contrast, dairy is a mostly small holder occupation, and milk is consumed within the country and contributes to rural employment to a larger extent. Accordingly, dairy development will be one of the key elements to directly improve small farmer livelihood in rural areas is suitable ecologies. In India, for example, small holder dairying is contributing significantly to employment and income generation particularly of women. Wide spread small holder participation in the sub-sector has lead to India moving from a large importer to an exporter of dairy products. Scale neutral dairy production technologies were important to this accomplishment but even more important was the improvement in infrastructure (rural

[11] Coffee and cocoa are quite similar in terms of production and processing technology. However, tea is technically differentiated from them, and as the result, the following empirical model does not include tea.

roads, electrification and water supply) which enabled the development of appropriate milk collection modalities and facilities.

In connection to infrastructure, coffee and cocoa would likely necessitate general transport infrastructure for export purposes. Obviously, transport infrastructure is in general essential for any agricultural products because of their nature of perishability. But an efficient transport network from farms to ports is of particular importance for export commodities. Telecommunications may also be necessary for the country to be fully integrated into the global supply chain and marketing system.

As well as accessibility which depends on roads, dairy production needs water and electricity critically.[12] Water has to be provided for animal drinking purposes and sanitary production, and electricity is most critical for cooling milk on farm or at nearby collection points. Fresh milk is highly perishable and is rendered completely unfit for consumption fresh or for processing if not cooled within four to eight hours depending on the ambient conditions.

On a simple correlation basis, nonetheless, the role of infrastructure assets seems weakly correlated as a facilitator of future production and growth of coffee, cocoa and milk production (Table 4).[13] The annual growth rate in each commodity production is calculated by volume growth plus the growth rate in real international commodity prices. This clearly could not mean that infrastructure would be useless. Rather, the potential infrastructure impacts might be rather dynamic; public infrastructure would directly reduce production and transport costs and thus raise sales. At the same time, the increased sales would further lower product prices due to economies of scale in production. In our sample, all commodities seem to exhibit economies of scale to a certain extent (Figures 6 to 8). But the degree of scale

[12] The importance of roads for diary development has been well documented (e.g., Mudavadi *et al*., 2001; Staal *et al*., 2003).

[13] Table 4 considers the impact of infrastructure stocks, rather than investment (flow). Moreover, the infrastructure-to-growth causality is assumed.

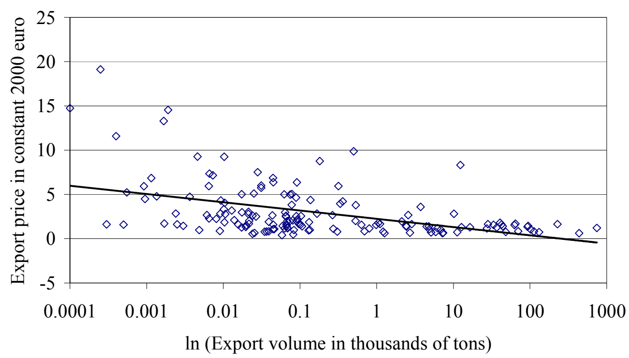
economies is not the same among commodities. Whether infrastructure after all has a positive or negative impact depends on the price elasticity and economies of scale.

Table 4. Correlation between commodity-specific growth and infrastructure development, 2001-04

	Coffee		Cocoa		Milk	
	Obs.	Cor.	Obs.	Cor.	Obs.	Cor.
Road density $_{2000}$	70	0.077	54	-0.022	167	-0.251
Rural access index $_{1993\text{-}2003}$	71	-0.030	55	0.080	163	-0.020
Teledensity $_{2000}$	73	0.160	55	0.061	175	-0.183
Rural teledensity $_{2000}$	54	0.185	39	0.134	128	-0.094
Electricity consumption $_{2000}$	46	-0.003	34	0.069	125	-0.173
Agri. Power consumption $_{2000}$	10	0.079	8	0.004	61	-0.138
Water access $_{1990}$	55	0.088	39	0.001	128	-0.075
Rural water access $_{1990}$	55	0.063	39	-0.054	128	-0.094

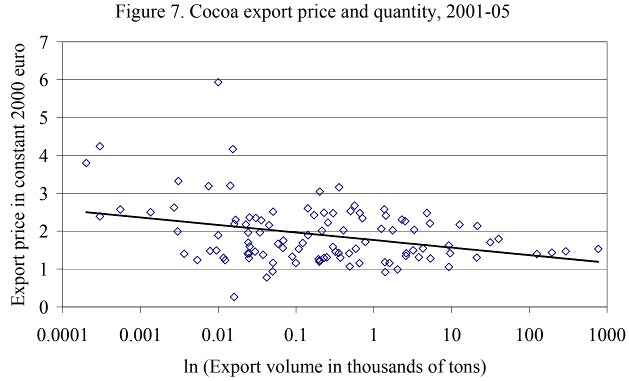
Source: Author's caluculations based on *WDI* , ITU (2002), IEA *Energy Statistics* , Roberts et al. (2006), *FAOSTAT* , and IMF *Primary Commodity Prices* .

Figure 6. Coffee export price and quantity, 2001-05



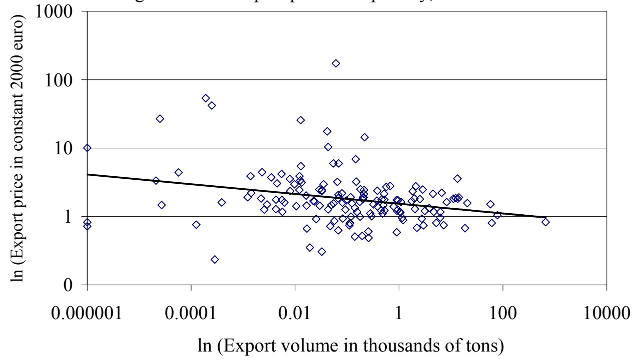
Source: Author's calculation based on *Eurostat* and *IFS* .

Figure 7. Cocoa export price and quantity, 2001-05



Source: Author's calculation based on *Eurostat* and *IFS* .

Figure 8. Milk export price and quantity, 2001-05



Source: Author's calculation based on *WITS COMTRADE database* and *IFS*.

III. METHODOLOGY AND DATA

Production. Public infrastructure investments are necessary to improve production and export efficiency in any industry. Consider a representative farmer *j*, who produces (and exports) agricultural commodity *k* and maximizes the following profit function:

$$\pi_{jk} = \left[p^*_{jk} - ER_j MC(INF_j, W_j, s_{jk}\overline{M}_k)\right]s_{jk}(p^*)\overline{M}_k - FC_{jk} \tag{1}$$

For each commodity *k*, p^*_{jk} and s_{jk} are the unit price and market share of country *j*, respectively. FC_{jk} is the fixed cost of production. $\overline{M}_k$ denotes the potential market size of product *k*. The marginal cost (MC_{jk}) is assumed to be shifted depending on the level of public infrastructure (INF_j), weather conditions (W_j) and the volume of sales. *ER* is the exchange rate of the foreign against the local currency. Under some reasonable assumptions, we consider the following supply function:[14]

$$\ln p^*_{jk} = \beta_0 + \beta_1 INF_j + \beta_2 \Delta ER_j + W_j{}'\beta_3 + \beta_4 \ln s_{jk} + c_j + \varepsilon_{1jk} \tag{2}$$

[14] Essentially, it is assumed that the derivative of demand quantity with respective to price is constant.

Demand. From the consumer point of view, suppose that consumer or importer *i* decides to purchase one unit of agricultural commodity from a variety of country-brands $j = 0, \cdots, J$, and maximizes the following utility function:

$$u_{ijk} = \alpha_0 + \alpha_1 \ln p_{jk} + x_j{}'\alpha_2 + \Delta\xi_{jk} + \varepsilon_{2ijk} \tag{3}$$

where x_j and $\Delta\xi_{jk}$ are a set of brand-specific characteristics and a brand-specific deviation from the brand-specific mean valuation. When assuming that the idiosyncratic error term is independently and identically distributed according to Type I extreme value distribution, such as $\exp(-\exp(-\varepsilon))$, we will have the following conventional market share equation:

$$\ln s_{jk} - \ln s_{0k} = \alpha_0 + \alpha_1 \ln p_{jk} + c_j + \Delta\xi_{jk} \tag{4}$$

where s_{0k} is the share of an outside option $j = 0$. For empirical simplicity, brand-specific characteristics are represented by the country-fixed effect in Equation (4).

Estimation method. Following the conventional demand-supply system equation literature (e.g., Epple and McCallum, 2006), Equations (2) and (4) are jointly estimated by the three-stage least squares (3SLS) technique, because price ($\ln p^*_{jk}$) and quantity ($\ln s_{jk}$) are interdependent on one another in the two equations. One of the great advantages of this technique, compared with a simple production function approach, is that both supply and demand sides are explicitly incorporated. In the production function approach, the demand response is usually ignored, and whether the endogeneity matters may depend merely on a statistical test.

Endogeneity. Infrastructure development is one of the endogenous variables in the growth context, even though it is empirically shown that growth of each agricultural commodity production is weakly associated with infrastructure stocks (Table 4). Two approaches are used to deal with this problem. First, lagged infrastructure variables are adopted. Second, the contemporaneous values of infrastructure are used but instrumented by their lagged values if they are available. In the latter case, the lagged infrastructure variables are additional instrumental variables in the usual 3SLS setting. On the other hand, both weather and exchange rate variables are treated as exogenous.

Commodities. To estimate coffee demand and supply, three coffee-related products are sampled from *Eurostat*: coffee and coffee substitutes (SITC3-071), cocoa (do. 072), and chocolate and food preparations containing cocoa (do. 073). Tea is another major farm product in Africa, but it is technically differentiated in production and processing; thus tea is not included. In the case of dairy, again, three milk-related products are chosen from the *WITS COMTRADE* database: milk and cream (SITC3-022), butter and other fat of milk (do. 023), and cheese and curd (do. 024). The advantage of pooling data from more than one subcategory is that it allows us to control for unobservable country-specific characteristics in both supply and demand equations, while maintaining a reasonable assumption of a common production function.

Market definition. As a potential market for coffee and cocoa, we focus on the European import market. Europe is the main export destination for many African producers, and European countries are largely dependent on imports for coffee and cocoa. The potential market size is defined as the total imports of EU25 from the world. While European consumers are supposed to purchase one unit of coffee or cocoa from extra-EU countries, the outside option would be to buy coffee and cocoa from intra-EU countries.[15] Both intra- and extra-EU trade data are available in *Eurostat*.

[15] The available data do not distinguish imports from outside the region and re-exports within the region. But the data show that about 80 percent of total coffee imports of EU member countries are associated with extra-EU imports.

For dairy products, the size of Africa's potential import market is defined as five percent of the total volume of production in the region.[16] The idea behind this is that dairy products are primarily expected to be consumed locally, and thus the potential market may be very small. Given that, each consumer in Africa is assumed to buy one unit of milk from other countries. Recall that the current regional milk import market is thin but *does* exist. Some countries are importing dairy products from their neighboring countries. One of the critical assumptions for this definition to be valid is that the domestic and international markets are not completely separated. In principle, the domestic market is linked to the international market, because trade arbitrage would take place if there is a significant difference between the internal and external prices.

On the other hand, when consumers choose not to import dairy products, the outside option is to purchase domestic products. Dairy production data come from *FAOSTAT*.[17] On the other hand, dairy exports data are collected from the *WITS COMTRADE* database.

Quantity and price. Both market share and price variables take the five-year (from 2001 to 2005) average to avoid possible data fluctuation in the short run. Prices are the export value (millions of constant 2000 euro) divided by the volume of exports (millions of kilograms). Recall that the sample includes only one 5-year period.

Infrastructure variables. Four agriculture-related infrastructure proxies are available: rural access index, rural telecommunications adoption index, rural water access, and agricultural electricity consumption per capita. They are relevant to agriculture but not specific to it. The first is the rural access index, which measures the share of rural residents with access to major roads (Roberts *et al*., 2006). It is not panel but cross-sectional data from 178 countries for 1993-2003. Unfortunately, two-third of the data is associated with the period: 2001-05.

[16] The amount of dairy exports is subtracted, though it is very small.

[17] For milk production, it includes all kinds of milk (i.e., cow (SITC4-0882), buffalo (0951), sheep (0982), goat (1020), and camel milk (1130)). For butter products, butter and ghee (do. 1811) data are used. All kinds of cheese (do. 1745) are used for the cheese item.

Given our empirical model, therefore, it is difficult to solve the endogeneity issue associated with this index.

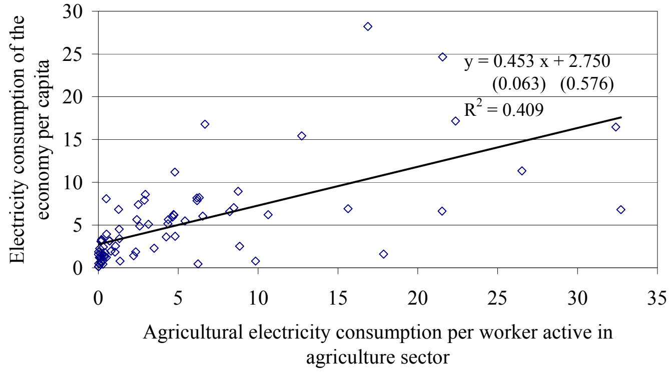
Second, the rural ICT adoption index is available for most countries; to take into account the possible digital divide between urban and rural areas the index is calculated by multiplying the sum of fixed line and cellular phone users per capita by the ratio of teledensity outside the largest city to teledensity (Lio and Liu, 2006). Unfortunately, the original data of teledensity—for only main lines—in the largest city and the rest of the areas are no longer published. The latest available data are for 2000 (ITU, 2002).[18] We use the teledensity outside the largest city in 2000 as a proxy of lagged rural telecommunications infrastructure.

Third, the share of rural residents with access to improved water is used for a proxy of water infrastructure development in rural areas. The data in 1990 and 2004 are available for most countries in *World Development Indicators*. The share of irrigated land to total cropland is also used for our complementary analysis.

Finally, the data on electricity consumption for agricultural purposes are available from *Energy Statistics* by International Energy Agency, but only for a limited number of countries. Particularly in Africa, less than ten countries are covered. We divide the total agricultural electricity consumption by the number of workers who are active in the agriculture sector. As commonly believed, it is true that agricultural areas are lagging behind in electrification (Figure 9). At the same time, however, there appears to be a significant positive association between overall and agricultural electricity consumption.

[18] After 2002, no mainline teledensity data in the largest city, urban and rural areas are reported in International Telecommunication Union's *World Telecommunication Development Report*.

Figure 9. Overall and agricultural electricity consumption
(In MWh)



Source: Author's calculation based on *Energy Statistics* and *WDI*.

In addition to the above four variables, the traditional general infrastructure variables are also taken from *World Development Indicators*: road density, teledensity, electricity consumption per capita and water access. Table 5 summarizes the data availability of our infrastructure variables. When the lagged value is not available, our methodologies cannot be applied. This is unavoidable because available infrastructure data are quite limited.

Table 5. Some available infrastructure variables

	Lagged (before 2000)	Current (2001-05)
Road density	√	√
Rural access index		√
Teledensity	√	√
Rural teledensity	√	
Electricity consumption	√	√
Agri. power consumption	Limited	Limited
Water access	√	√
Rural water access	√	√

Other variables. Weather data are provided from the National Oceanic and Atmospheric Administration (NOAA) database, the Global Historical Climatology Network (GHCN) Version 2. We create four variables to control regional heterogeneity among our sample countries: average deviation of summer/winter temperature from the long-term trend in 1990-2000, and average deviation of summer/winter precipitation from the long-term trend in

1990-2000. Summer data are taken from either January or July whichever has higher monthly temperature.

Finally, the exchange rate data are calculated from *International Financial Statistics*; the exchange rate variable in our model is defined as annual changes in the euro per the local currency. The exchange rate appreciation is expected to increase product prices at the destination market and reduce competitiveness.

IV. Estimation Results and Policy Implications

Coffee and cocoa. The three-stage least squares estimation is performed for coffee and cocoa, and dairy products separately (Tables 6 and 8). First of all, in the coffee and cocoa case, the price coefficient is negative and significant; an increase in product prices would lower competitiveness and reduce the market share.

Table 6. Coffee, cocoa and chocolate: three stage least squares estimates

	With lagged infrastructure variables						With current infrastructure variables instrumented				
Market share equation 1/ 2/											
$\ln p^{*}_{jk}$ 3/	-3.365 ***	-2.418 ***	-5.823 ***	-1.922 *	-2.418 ***	-2.418 ***	-7.292 ***	-2.418 ***	-1.922 *	-2.418 ***	-2.418 ***
	(0.908)	(0.760)	(0.745)	(1.112)	(0.760)	(0.761)	(0.808)	(0.763)	(1.112)	(0.758)	(0.764)
Constant	-8.234 ***	-8.293 ***	…	-10.285 ***	-8.293 ***	-8.293 ***	…	-8.293 ***	-10.285 ***	-8.293 ***	-8.293 ***
	(1.125)	(1.081)	…	(1.248)	(1.081)	(1.082)	…	(1.085)	(1.248)	(1.078)	(1.087)
Price equation 4/											
Road density	-0.193 **						-0.180 *				
	(0.097)						(0.095)				
Teledensity		0.483 *						0.349			
		(0.293)						(0.269)			
Rural teledensity			0.091								
			(0.056)								
Electricity consumption				0.009					0.009		
				(0.015)					(0.014)		
Water access					0.019 ***					0.010 ***	
					(0.006)					(0.004)	
Rural water access						0.015 ***					0.017 ***
						(0.005)					(0.005)
ΔER	0.023 *	0.007	0.004	-0.005	0.008	-0.003	0.021 *	0.011	-0.005	0.014	0.005
	(0.012)	(0.012)	(0.009)	(0.007)	(0.011)	(0.011)	(0.012)	(0.011)	(0.007)	(0.010)	(0.010)
$\ln s_{jk}$	-0.150 ***	-0.186 ***	-0.132 ***	-0.159 ***	-0.182 ***	-0.124 ***	-0.151 ***	-0.218 ***	-0.159 ***	-0.176 ***	-0.132 ***
	(0.049)	(0.045)	(0.044)	(0.049)	(0.060)	(0.044)	(0.052)	(0.049)	(0.049)	(0.058)	(0.044)
Constant	0.176	-0.922 *	-0.150	-0.890	-2.176 **	-1.387 *	0.164	-1.094 **	-0.890	-1.220	-1.576
	(0.505)	(0.486)	(0.313)	(0.552)	(0.972)	(0.715)	(0.534)	(0.548)	(0.552)	(0.774)	(0.748)
Obs.	176	189	137	228	166	163	144	186	228	163	157
Weather variables	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Number of country dummies	62	67	49	80	58	57	50	66	80	57	55
Chi-square statistics											
Market share equation	198.9 ***	236.7 ***	1786.2 ***	215.4 ***	222.7 ***	222.2 ***	1943.7 ***	233.9 ***	215.4 ***	220.2 ***	212.1 ***
Price equation	173.5 ***	191.2 ***	167.3 ***	197.9 ***	167.8 ***	192.1 ***	119.5 ***	158.7 ***	197.9 ***	175.9 ***	194.1 ***

Source: Author's calculations.

1/ The dependent variable is $\ln s_{jt}$.

2/ The constant term in the market share equation is dropped due to multicollinearity with country-specific dummy variables.

3/ The estimated price coefficient only marginally varies among models, because instrumental variables adopted are almost identical.

4/ The dependent variable is $\ln p^{*}_{jk}$

Second, transport infrastructure is most important to promote the coffee and cocoa sectors.[19] This is consistent with our prior expectation; the overall road connection from farms to primary processing facilities and to major ports are the main determinant of the market performance, because coffee and cocoa are among typical high-value commodities and are exported abroad. This result is not contradictory to the existing study on another high-value agriculture commodity, beef (Iimi, 2007).

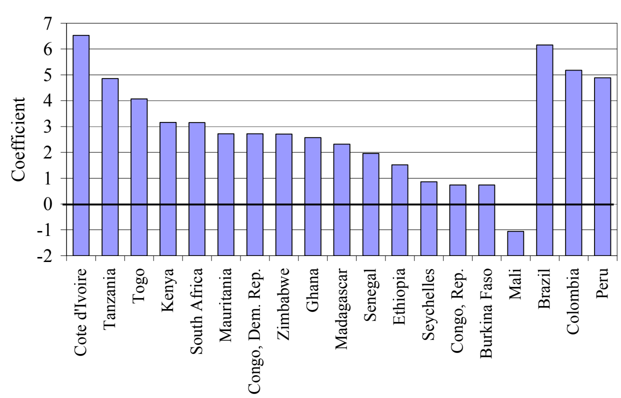
Despite our prior expectation, the impact of telecommunications infrastructure is not significant. The reason may be the measurement error problem. The telecommunications industry is rapidly developing in both quantity and quality terms; the traditional teledensity may not be able to capture such rapid development in the recent years. Recall that our lagged

[19] There is no evidence to support that agriculture- or rural-related infrastructure is of particular importance in this area, though there are only a few comparable specifications, i.e., telecommunications and water infrastructure provision.

rural telecommunications variable covers only main lines. This obviously underestimates the recent mobile network and Internet development.

In fact, the estimated country-specific fix-effects, rather than the teledensity coefficients, may suggest that branding is very important in this area. The country dummy variables, of which the estimated coefficients are shown in Figure 10, explain much of consumer preferences in our estimated demand function. It reveals that some African coffee exporters, such as Cote d'Ivoire and Tanzania, seem to benefit from their invisible preferred status, including name values. While one of the highest name recognitions in the region, Kenya, has a relatively high coefficient, another, Ethiopia, is projected to having a relatively low value. Most of the others may be lagging behind in establishing their brand names. The evidence shows that the mega exporters in the world, such as Brazil and Colombia, have the relative advantage in gaining worldwide recognition and having a large bargaining power with distributors. Accordingly, telecommunications infrastructures are essential for coffee and cocoa producers to get full access to market information and to be integrated into the global supply chain. African countries may have to invest more in communication technologies to improve their marketing competitiveness.

Figure 10. Estimated country-specific brand effects in coffee and cocoa production



The water access variable seems contradictory. It may be inappropriate to measure the water infrastructure impact on coffee and cocoa production by this variable, because the quality of water for agricultural purposes is not that high, i.e., access to improved water sources (e.g., a household connection, public standpipe, and protected well or spring). Rather, irrigation facility development may be a better proxy for agricultural water infrastructure in this case. In fact, when the ratio of irrigated land to total cropland is adopted, it has been found that irrigation could reduce the coffee production prices (Table 7). Although the water access coefficients are still significant, the coefficient of irrigation penetration rate is significant and negative.

Table 7. Coffee, cocoa and chocolate: three stage least squares estimates with irrigation

	With lagged infrastructure variable			With current infrastructure variable instrumented		
Market share equation 1/ 2/						
$\ln p^*_{jk}$ 3/	-2.418 ***	-5.480 ***	-5.480 ***	-2.418 ***	-5.480 ***	-5.480 ***
	(0.769)	(0.808)	(0.808)	(0.769)	(0.790)	(0.797)
Constant	-8.293 ***	…	…	-8.293 ***	…	…
	(1.094)	…	…	(1.095)	…	…
Price equation 4/						
Irrigation	-0.0127	-0.579 *	-0.596 *	-0.012	-1.405 ***	-0.207
	(0.575)	(0.352)	(0.352)	(0.521)	(0.497)	(0.468)
Water access		0.018 ***			0.008 **	
		(0.006)			(0.003)	
Rural water access			0.017 ***			0.018 ***
			(0.005)			(0.005)
ΔER	-0.010	0.007	-0.001	-0.010	0.021 **	0.006
	(0.012)	(0.010)	(0.011)	(0.012)	(0.011)	(0.011)
$\ln s_{jk}$	-0.257 ***	-0.131 ***	-0.122 ***	-0.257 ***	-0.140 ***	-0.132 ***
	(0.059)	(0.044)	(0.043)	(0.058)	(0.044)	(0.043)
Constant	-1.463 **	-1.555 **	-1.380 **	-1.463 **	-0.442	-1.587 **
	(0.637)	(0.750)	(0.705)	(0.636)	(0.589)	(0.726)
Obs.	175	155	155	172	149	146
Weather variables	Yes	Yes	Yes	Yes	Yes	No
Number of country dummies	62	55	55	61	53	52
Chi-square statistics						
Market share equation	219.9 ***	1498.6 ***	1498.6 ***	217.4 ***	1476.3 ***	1403.4 ***
Price equation	127.6 ***	180.6 ***	182.0 ***	127.9 ***	185.4 ***	184.5 ***

Source: Author's calculations.

1/ The dependent variable is $\ln s_{jt}$.

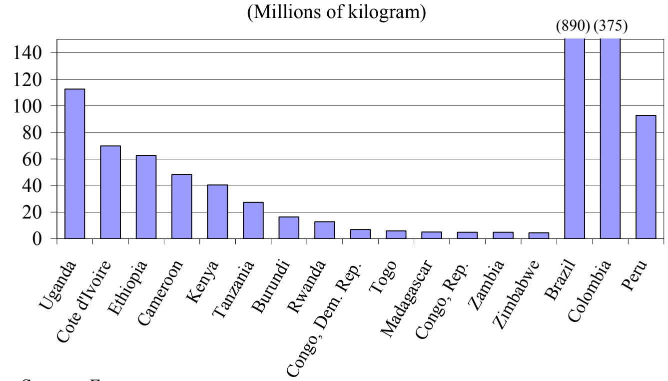
2/ The constant term in the market share equation is dropped due to multicollinearity with country-specific dummy variables.

3/ The estimated price coefficient only marginally varies among models, because instrumental variables adopted are almost identical.

4/ The dependent variable is $\ln p^*_{jk}$

Third, economies of scale have a large role to play in coffee and cocoa production and exports. The quantity coefficient in the market share equation is significantly negative for all the models. As shown in Figure 11, the majority of coffee and cocoa producers in Africa still remain relatively small. It will be a challenge, but also an opportunity, to improve their competitiveness by increasing their bargaining power through collective action, for example marketing cooperatives.

Figure 11. Volume of coffee exports to EU market, 2001-05
(Millions of kilogram)



Source: *Eurostat* .

Exchange rate appreciation may hamper competitiveness improvement of coffee and cocoa products, as expected. But this is somewhat inconclusive. The weather conditions, though omitted from the table, are generally significant in a statistical sense. Hotter-than-usual summer and cooler-than-usual winter temperatures are more productive. More precipitation in summer is welcome, but more precipitation in winter would raise production costs.

Milk. As shown in Table 8, the price coefficient tends to be significantly negative. Regarding the infrastructure impacts, only water infrastructure seems to contribute to increasing dairy productivity. Of particular note, the positive effect of water access in rural areas has been found robust in a statistical sense. By contrast, the statistical significance of the general water access coefficient is lost in the model where the current infrastructure variable is used.

Similar to the case of coffee and cocoa, economies of scale are likely to matter in the dairy industry. However, the evidence is less conclusive than the coffee case; it depends on specification. This may be intuitively acceptable because the size of dairy production is not large in Africa, except South Africa (Figure 12). Still, the table indicates that there are many opportunities for African countries, for instance Kenya, to develop neighboring markets within the region, rather than importing dairy products from European countries. Current efforts to promote intraregional trade could pay large dividends to the dairy industry.

The exchange rate is unlikely to affect the market performance in the dairy sector, possibly because most of dairy products are domestically consumed. Unlike coffee and cocoa, weather seems less relevant to dairy sector productivity. In Table 7, the models do not include weather variables; the null hypothesis that all weather variables are indifferent from zero can easily be rejected by the standard Wald test.

Table 8. Milk, butter and cheese: three stage least squares estimates

	With lagged infrastructure variables							With current infrastructure variables instrumented by lagged values					
Market share equation 1/ 2/													
$\ln p^*_{jk}$ 3/	-5.765 ***	-5.765 ***	-4.788 ***	-1.246 ***	-1.846 ***	-3.201 ***	-3.201 ***	-5.765 ***	-5.765 ***	-1.246 ***	-1.846 ***	-3.201 ***	-3.201 ***
	(1.705)	(1.699)	(1.049)	(0.340)	(0.439)	(0.982)	(0.985)	(1.777)	(1.677)	(0.340)	(0.439)	(0.993)	(1.001)
Price equation 4/													
Road density	0.035							0.035					
	(0.113)							(0.116)					
Teledensity		-0.505							-0.212				
		(0.403)							(0.288)				
Rural teledensity			0.087										
			(0.086)										
Electricity consumption				0.009						0.009			
				(0.026)						(0.024)			
Agri. power consumption					-0.008						0.011		
					(0.008)						(0.017)		
Water access						-0.020 ***						0.012 **	
						(0.007)						(0.006)	
Rural water access							-0.021 ***						-0.040 ***
							(0.007)						(0.014)
ΔER	0.007	0.009	-0.006	-0.002	0.080 **	0.004	0.004	0.008	0.009	-0.002	0.077 **	0.021 **	0.002
	(0.009)	(0.010)	(0.010)	(0.010)	(0.037)	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)	(0.037)	(0.009)	(0.009)
$\ln s_{jk}$	-0.170 ***	-0.156 ***	-0.085	-0.084 *	-0.166 ***	-0.113 ***	-0.131 ***	-0.169 ***	-0.155 ***	-0.085	-0.165 ***	-0.258 ***	-0.103 ***
	(0.052)	(0.047)	(0.054)	(0.050)	(0.061)	(0.038)	(0.037)	(0.054)	(0.048)	(0.050)	(0.061)	(0.055)	(0.039)
Constant	0.117	0.290	-0.174	0.093	0.362	1.819 ***	1.571 ***	0.118	0.314	0.092	0.314	-0.582	3.086
	(0.454)	(0.454)	(0.620)	(0.459)	(0.469)	(0.625)	(0.565)	(0.469)	(0.534)	(0.460)	(0.465)	(0.569)	(1.004)
Obs.	278	291	210	245	135	240	237	235	288	245	135	231	225
Weather variables	No	No	No	No	No	No	No	No	No	No	No	No	No
Number of country dummies	100	105	76	86	47	85	84	83	104	86	47	82	80
Chi-square statistics													
Market share equation	1205.6 ***	1297.8 ***	1639.8 ***	4789.4 ***	1336.4 ***	2382.5 ***	2354.1 ***	939.1 ***	1305.4 ***	4789.4 ***	1336.4 ***	2240.1 ***	2177.1 ***
Price equation	337.9 ***	357.8 ***	270.6 ***	238.5 ***	96.9 ***	270.9 ***	271.4 ***	253.2 ***	363.8 ***	238.5 ***	97.0 ***	244.2 ***	241.6 ***

Source: Author's calculations.

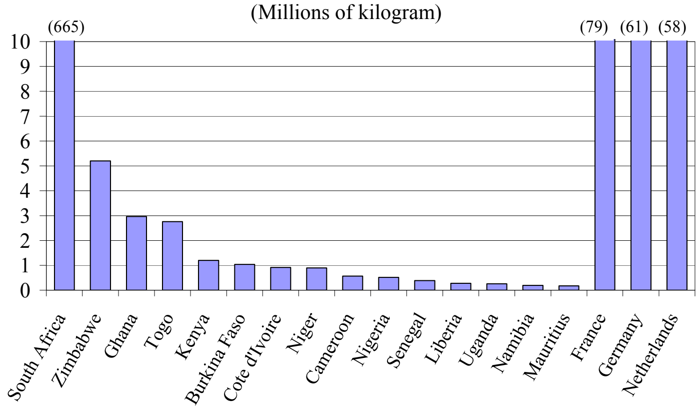
1/ The dependent variable is $\ln s_{jt}$.

2/ The constant term in the market share equation is dropped due to multicollinearity with country-specific dummy variables.

3/ The estimated price coefficient only marginally varies among models, because instrumental variables adopted are almost identical.

4/ The dependent variable is $\ln p^*_{jk}$

Figure 12. Volume of milk exports to African market, 2001-05
(Millions of kilogram)



Source: *WITS COMTRADE* database.

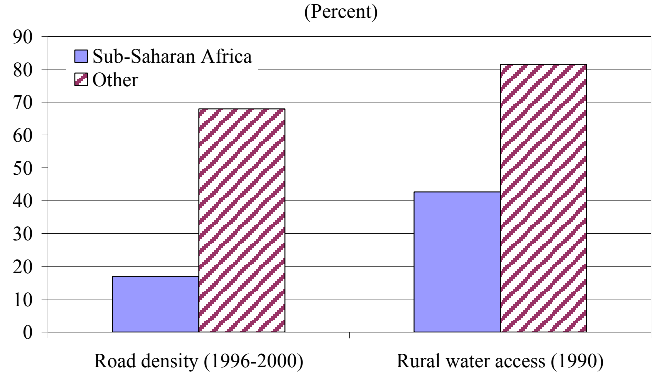
Implied growth impacts. Based on our estimated supply and demand of each farm product, the elasticity of commodity sales with respect to infrastructure development is calculated as follows:

$$\begin{aligned}\frac{\partial(p_k^* s_k \overline{M}_k)}{\partial INF}\frac{INF}{p_k^* s_k \overline{M}_k} &= \frac{\partial p_k^*}{\partial INF}\frac{INF}{p_k^*} + \frac{\partial s_k}{\partial INF}\frac{INF}{s_k} \\ &= \left[\varepsilon_1 + \frac{\varepsilon_1\varepsilon_2\varepsilon_3}{1-\varepsilon_2\varepsilon_3}\right] + \frac{\varepsilon_1\varepsilon_2}{1-\varepsilon_2\varepsilon_3}\end{aligned} \tag{5}$$

where $\varepsilon_1 = \hat{\beta}_1 INF_j$, $\varepsilon_2 = \hat{\alpha}_1$, and $\varepsilon_3 = \hat{\beta}_4$. The first term in Equation (5) is the direct impact of infrastructure development to reduce production costs. The second is the total effect of scale economies in production, which stem from increases in production generated by the initial price reduction by infrastructure improvement. These first two comprise the price elasticity associated with infrastructure development. The last term in the equation is the total demand elasticity with respect to price.

Two infrastructure variables are examined; road density and rural water access for coffee and dairy, respectively. As suggested above, they are among the strongest infrastructure drivers for growth. Sub-Saharan Africa is, again, lagging behind in developing these infrastructures (Figure 13).

Figure 13. Infrastructure development in sample countries
(Percent)



Source: *World Development Indicators* .

The implied total elasticity of coffee exports with respect to infrastructure development is estimated at about 0.1-0.5 for African countries (Table 9). The elasticity varies among countries. Theoretically, the empirical exports elasticity could be positive and negative. In our sample, the quantity impact tends to overwhelm the price effect, meaning that infrastructure development would lead to an increase in exports. A 1 percent improvement in road density would lower production and export costs by 0.01-0.2 percent. On the other hand, the quantity might increase by 0.1-0.7 percent.

Assuming a 1 percent increase in the infrastructure measurement, Burundi and Rwanda would be among the largest gainers in terms of incremental relative to GDP. In other countries, the growth impact of road improvement would be more limited at about 0.02 percent of GDP.

Table 9. Coffee: Implied infrastructure elasticities and growth impact

	Export volume (million kg)	$\frac{\partial p_k^*}{\partial INF}\frac{INF}{p_k^*}$	$\frac{\partial s_k}{\partial INF}\frac{INF}{s_k}$	Total elasticity	ΔGDP (million US$)	% of GDP
Cote d'Ivoire	69.9	-0.06	0.21	0.15	12.0	0.074
Ethiopia	62.6	-0.01	0.04	0.03	3.6	0.033
Cameroon	48.2	-0.03	0.10	0.07	3.5	0.021
Kenya	40.5	-0.04	0.15	0.10	10.5	0.056
Tanzania	27.4	-0.04	0.13	0.09	4.1	0.033
Burundi	16.5	-0.22	0.74	0.52	15.3	1.911
Rwanda	12.8	-0.19	0.64	0.45	10.3	0.479
Guinea	7.4	-0.05	0.16	0.12	0.8	0.024
Congo, Dem. Rep.	6.8	-0.03	0.09	0.06	0.6	0.009
Togo	5.9	-0.05	0.18	0.13	0.8	0.036
Madagascar	5.1	-0.03	0.11	0.08	0.4	0.008
Congo, Rep.	4.8	-0.01	0.05	0.03	0.2	0.005
Zambia	4.8	-0.04	0.12	0.08	0.8	0.011
Zimbabwe	4.5	-0.02	0.06	0.04	0.4	0.011
Central African Rep	2.7	-0.01	0.05	0.04	0.1	0.007
Malawi	2.4	-0.07	0.23	0.16	0.7	0.036
Sierra Leone	1.3	-0.06	0.21	0.15	0.2	0.013
Ghana	1.2	-0.07	0.23	0.16	0.2	0.002

In the case of milk production, the result is somewhat less reliable. The implied elasticity of exports with respect to infrastructure development is estimated at 2 to 5 (Table 10). Generally, the effect of economies of scale is large; because the dairy demand looks very price-elastic, farmers who achieve even a small reduction in production costs would likely take advantage of scale economies. In addition to South Africa, which is a single large exporter in the region, Liberia, Nigeria, Togo and Zimbabwe may be able to increase milk production relative to GDP by improvements in rural water access.

Table 10. Milk: Implied infrastructure elasticities and growth impact

	Export volume (million kg)	$\frac{\partial p_k^*}{\partial INF}\frac{INF}{p_k^*}$	$\frac{\partial s_k}{\partial INF}\frac{INF}{s_k}$	Total elasticity	ΔGDP (million US$)	% of GDP
South Africa	665.02	-2.5	7.9	5.45	4,149.5	1.732
Zimbabwe	5.20	-2.5	7.9	5.45	31.6	0.938
Ghana	2.96	-1.3	4.2	2.92	8.9	0.083
Togo	2.76	-1.3	4.2	2.92	10.3	0.469
Kenya	1.20	-1.1	3.4	2.37	3.5	0.019
Burkina Faso	1.04	-1.2	3.9	2.69	4.5	0.087
Cote d'Ivoire	0.91	-2.4	7.7	5.29	8.1	0.050
Niger	0.90	-1.3	4.0	2.76	6.0	0.176
Cameroon	0.57	-1.1	3.6	2.45	5.2	0.031
Nigeria	0.52	-1.2	3.8	2.61	4.0	0.004
Senegal	0.39	-1.8	5.6	3.87	2.9	0.035
Liberia	0.28	-1.2	3.9	2.69	1.1	0.210
Uganda	0.26	-1.4	4.6	3.16	0.6	0.006
Namibia	0.20	-1.5	4.8	3.32	0.5	0.008
Angola	0.15	-1.4	4.6	3.16	2.1	0.006
Zambia	0.14	-1.0	3.1	2.13	0.2	0.003

Limitations of the analysis. It is worth noting that the above discussion may have four limitations. First, the empirical model is valid in only the partial equilibrium sense. It can provide a good inference when examining the marginal impact of infrastructure development on exports or growth. It cannot answer the question about what would happen if all countries achieve large infrastructure improvements at the same time. For the same reasons, the model *does* ignore the possible reactions in other markets of the economy, e.g., other goods and labor markets.

Technically, second, the model focuses on the commodity import market to avoid the lack of available data. The domestic markets could be inferred from our estimation results under the assumption that the internal and external markets are linked. However, this assumption may be violated in some countries that have considerable trade barriers.

Third, the model does not take into consideration the cost of infrastructure provision. In our case, the estimated growth impacts are mostly positive—though sometimes very small in terms of magnitude. However, the accurate net impact of infrastructure development may have to be measured accounting for the cost of public services.

Finally, infrastructure data are still problematic. There is no comprehensive infrastructure data specific to a particular industry. The above analysis may suffer from the measurement error problem. Efforts to correct this data paucity may be well justified. Availability of such date could facilitate evidence based decisions concerning infrastructure development that specifically targets rural growth using agriculture as the vehicle. This remains a weak area of most development strategies.

VI. CONCLUSION

Agricultural development is one of the key for growth in Africa. Aggregate agricultural growth is expected to be accelerated by public infrastructure provision. However, the potential infrastructure impact may vary across commodities.

The paper investigates two different types of farm products: coffee and cocoa, representing high-value export products; and milk, representing a domestic agricultural commodity. The available infrastructure data are quite limited. Some agriculture- or rural-related infrastructure proxies are used: rural teledensity, rural water access and irrigation penetration rate.

The estimation results indicate that agricultural production could be promoted by different infrastructures, depending on commodity. Roads and irrigation facilities could strengthen production efficiency in the coffee and cocoa industries. Telecommunications infrastructures are also important for branding these commodities. Conversely, dairy production requires more water in rural areas.

One of the policy implications is that African countries might have to invest more in communication technologies as well as water and transport infrastructures to improve their agricultural marketing competitiveness. Another is that, to maximize their bargaining power in the market, collective action, for example marketing cooperatives, may be useful. It is also shown that the marginal improvements in these key infrastructures could contribute about 0.1–0.4 percent of GDP, and possibly several percent, in some cases.

REFERENCES

Antle, John. 1983. Infrastructure and aggregate agricultural productivity: international evidence. *Economic Development and Cultural Change*, Vol. 31, pp. 609-619.

Bravo-Ortega, Claudio, Daniel Lederman. 2004. Agricultural productivity and its determinants: revisiting international experiences. *Estudios de Economía*, Vol. 31, pp. 133-163.

———. 2005. Agriculture and national welfare around the world: causality and international heterogeneity since 1960. Policy Research Working Paper No. 3499, the World Bank.

Broadman, Harry. 2007. *Africa's Silk Road: China and India's New Economic Frontier*. The World Bank, Washington D.C.

Buys, Piet, Uwe Deichmann, David Wheeler. 2006. Road network upgrading and overland trade expansion in Sub-Saharan Africa. Policy Research Working Paper No. 4097, the World Bank.

Calderón, César, Luis Servén. 2004. The effects of infrastructure development on growth and income distribution. Policy Research Working Paper No. 3400, the World Bank.

Canning, David. 1998. A database of world stocks of infrastructure, 1950-1995. *The World Bank Economic Review*, Vol. 12, pp. 529-47.

Delgado, Christopher, Nicholas Minot, Marites Tiongco. 2005. Evidence and implications of non-tradability of food staples in Tanzania, 1983-98. *The Journal of Development Studies*, Vol. 41, pp. 376-393.

Epple, Dennis, Bennett MxCallum. 2006. Simultaneous equation econometrics: the missing example. *Economic Inquiry*, Vol. 44, pp. 374-384.

Fan, Shenggen, Somchai Jitsuchon, Nuntaporn Methakunnavut. 2004. The importance of public investment for reducing rural poverty in middle-income countries: the case of Thailand. DSGD Discussion Paper No. 7, International Food Policy Research Institute.

Fan, Shenggen, Linxiu Zhang, Xiaobo Zhang. 2002. Growth, inequality, and poverty in rural China: the role of public investment. Research Report 125, International Food Policy Research Institute, Washington D.C.

Fay, Marianne, Tito Yepes. 2003. Investing in infrastructure: what is needed from 2000 to 2010? Policy Research Working Paper No. 3102, the World Bank.

Gardner, Bruce. 2005. Causes of rural economic development. *Agricultural Economics*, Vol. 32, pp. 21-41.

Iimi, Atsushi. 2007. Infrastructure and trade preferences for the livestock sector: empirical evidence from the beef industry in Africa. Policy Research Working Paper No. 4201, the World Bank.

International Telecommunication Union. 2002. *World Telecommunication Development Report 2002*, International Telecommunication Union, Geneva.

Lio, Monchi, Meng-Chun Liu. 2006. ICT and agricultural productivity: evidence from cross-country data, *Agricultural Economics*, Vol. 34, pp. 221-228.

Mlachila, M., Yang, Y. 2004. The end of textiles quotas: a case study of the impact on Bangladesh. IMF Working Paper WP/04/108, International Monetary Fund.

Morrison, Catherine. 1997. Economic performance, cost economies and pricing behaviour in the US and Australian meat products industries. *The Australian Journal of Agricultural and Resource Economics*, Vol. 31, pp. 361-83.

Mudavadi, P.O., K. Otieno, J.W. Wanambacha, J.O. Odenya, M. Odendo, O.K. Njaro. 2001. Smallholder dairy production and marketing in Western Kenya: a review of literature. Smallholder Dairy Project Collaborative Research Report.

Mundlak, Yair. 2000. *Agriculture and Economic Growth: Theory and Measurement*, Harvard University Press, Massachusetts.

Mundlak Yair, Donald Larson, Rita Butzer. 2002. Determinants of agricultural growth in Indonesia, the Philippines and Thailand. Policy Research Working Paper No. 2803, the World Bank.

———. 2004. Agricultural dynamics in Thailand, Indonesia and the Philippines. *The Australian Journal of Agricultural and Resource Economics*, Vol. 48, pp. 95-126.

Nordås, H.K. 2004. The global textile and clothing industry post the Agreement on Textiles and Clothing. WTO Discussion Paper No. 5, World Trade Organization, Geneva.

Reed, Michael, Sayed Saghaian. 2004. Measuring the intensity of competition in the Japanese beef market. *Journal of Agricultural and Applied Economics*, Vol. 36, pp. 113-121.

Roberts, Peter, Shyam KC, Cordula Rostogi. 2006. Rural access index: a key development indicator. Transport Papers TP-10, the World Bank.

Schultz, Theodore. 1964. *Transforming Traditional Agriculture*. Yale University Press, New Haven.

Staal, S.J., M. Waithaka, L. Njoroge, D.M. Mwangi, D. Njubi, A. Wokabi. 2003. Costs of milk production in Kenya: estimating from Kiambu, Nakuru and Nyandarua Districs. Smallholder Dairy Project Collaborative Research Report.

Tiffin, Richard, Xavier Irz. 2006. Is agriculture the engine of growth? *Agricultural Economics*, Vol. 35, pp. 78-89.

Timmer, Peter. 2002. Agriculture and economic development, in *Handbook of Agricultural Economics Vol. 2*, eds. by B. Gardner and G. Rausser, pp. 1487-1546, Elsevier Science, Amsterdam.

U.S. International Trade Commission. 2004. *Textiles and Apparel: Assessment of the Competitiveness of Certain Foreign Suppliers to the U.S. Market*. United States International Trade Commission, Washington D.C.

Williams, Timothy, B. Spycher, Iheanacho Okike. 2006. *Improving livestock marketing and intra-regional trade in West Africa: determining appropriate economic incentives and policy framework.* International Livestock Research Institute, Nairobi.

World Bank. 1994. *World Development Report: Infrastructure for Development*. The World Bank, Washington D.C.

———. 2005. *Agriculture and achieving the Millennium Development Goals*. The World Bank, Washington D.C.